U.S. DEPARTMENT OF ENERGY
Office of Science

# The DOE Atmospheric Radiation Measurement Program's LES ARM Symbiotic Simulation and Observation (LASSO) Workflow

## Initialization, Forcing and Multiscale Data Assimilation


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JPL Jet Propulsion Laboratory

Pacific Northwest NATIONAL LABORATORY

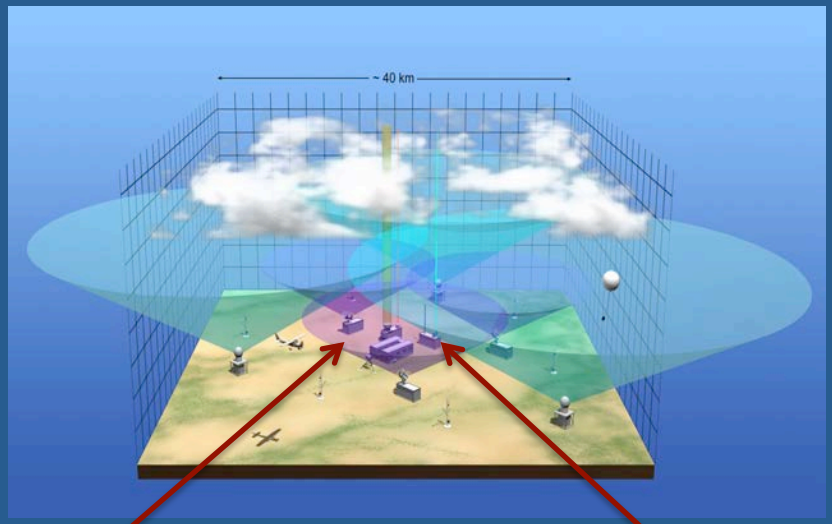
BROOKHAVEN NATIONAL LABORATORY

UCLA JIFRESSE

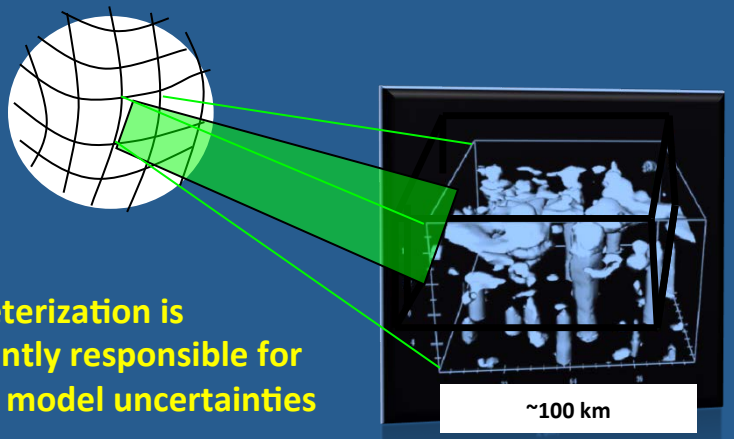
# The Atmospheric Radiation Measurement (ARM) Facility for Integrating Modeling with Observations

Dense observations are coupled with high-resolution process models to provide "4-dimensional data cubes" for parameterization development and process understanding

ARM Megasite Observing Network




Southern Great Plains (SGP) Site




Parameterization is dominantly responsible for climate model uncertainties

# LES ARM Symbiotic Simulation and Observation (LASSO)

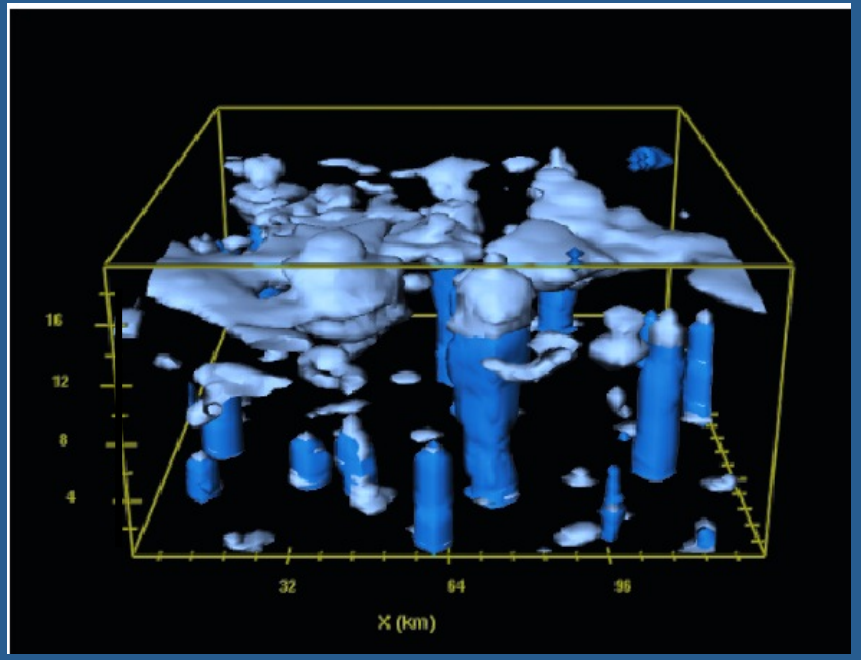
**LASSO is designed to generate an ever expanding library of LES simulations that will add value to ARM's observations. The goal is to expand beyond the typical case-specific mentality used in much of LES modeling.**

**Gustafson, et al., Poster A21D-0161 for Workflow**

- **Solves virtually all relevant dynamic scales**
- **Constrain LES using dense ARM measurements**
- **Provides 3D, time dependent fields of velocity, temperature, humidity, cloud, etc.**

**Vogelmann et al., Poster A21D-0163 for 4D Cube**

**LASSO Large Eddy Simulation (LES)**




- Models: WRF and SAM
- Domain: ~25 km
- Horizontal spacing: ~100 m
- …

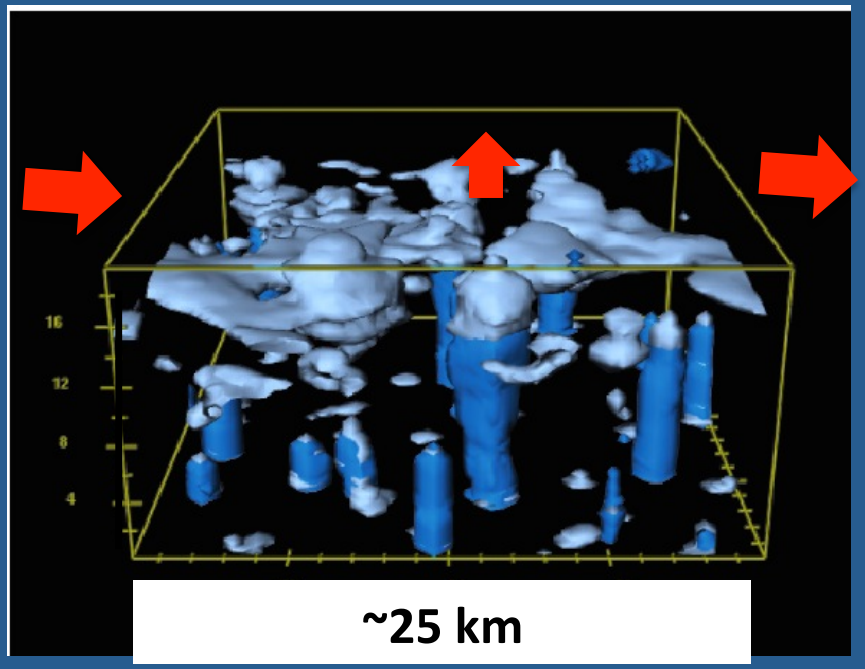
# LASSO LES Initialization and Large Scale Forcing

**Vertical Profiles for Initializing LES:**

- Temperature, moisture and winds, and hydrometeors (?)

**Large Scale Forcing:**

- Horizontal advection of temperature and moisture
- Vertical velocity
- Geostrophic winds
- Horizontal advection of hydrometeors (?)



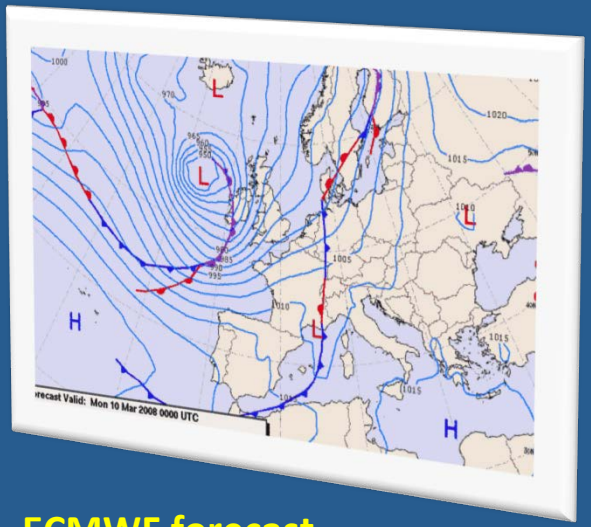

LES is driven by

- Large scale horizontal and vertical advection
- Surface sensible heat flux, latent heat flux, albedo and skin temperature

# Derivation of Large Scale Forcing

## Data Products form Meteorological Centers

- Forecasts or reanalysis from ECMWF, NCEP
- Lower spatial and temporal resolution
- Not all ARM observations assimilated
- …

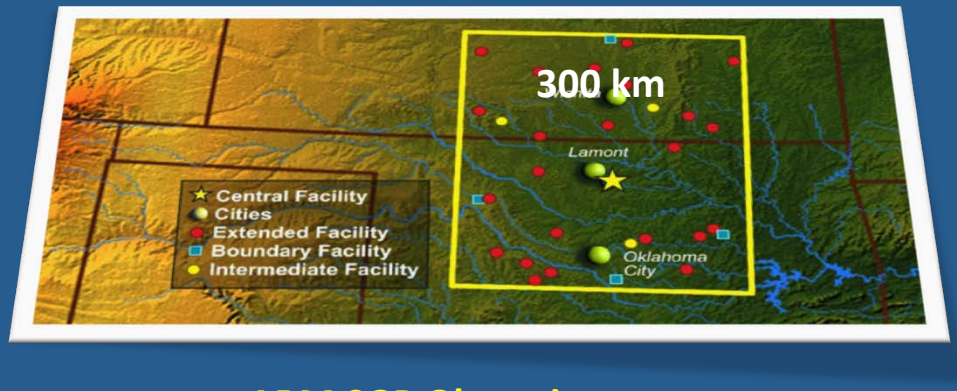



ECMWF forecast

## ARM Variational Analysis

(Xie et al. 2010, BAMS)

- 300 km area limited by the boundary facility
- Column averaged conditions only
- hydrometeors



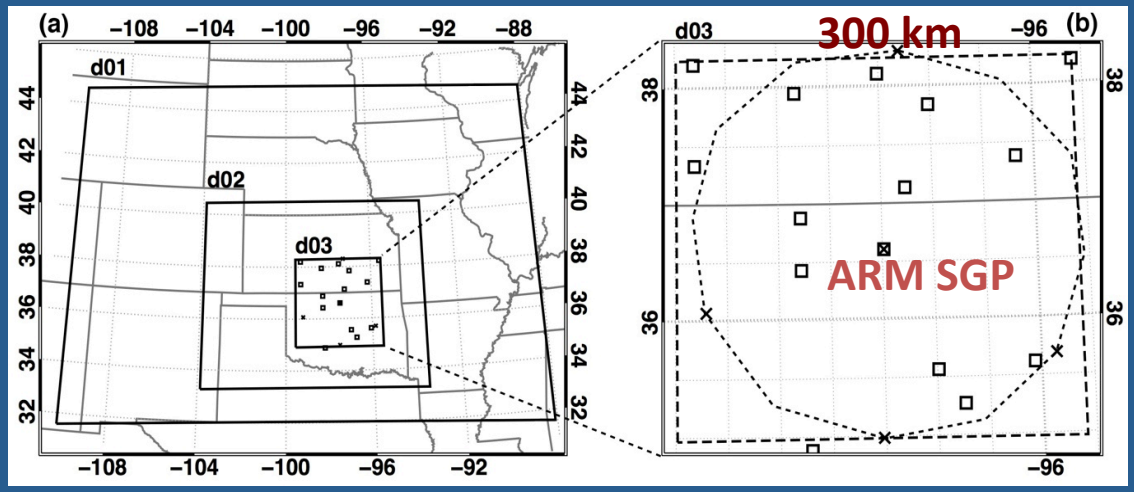

ARM SGP Observing

# Challenges and Requirements on Large Scale Forcing

1. Multi-scale/scale-aware forcing
2. Forcing for non-periodic domains
3. Cloud and precipitation related variables (?)

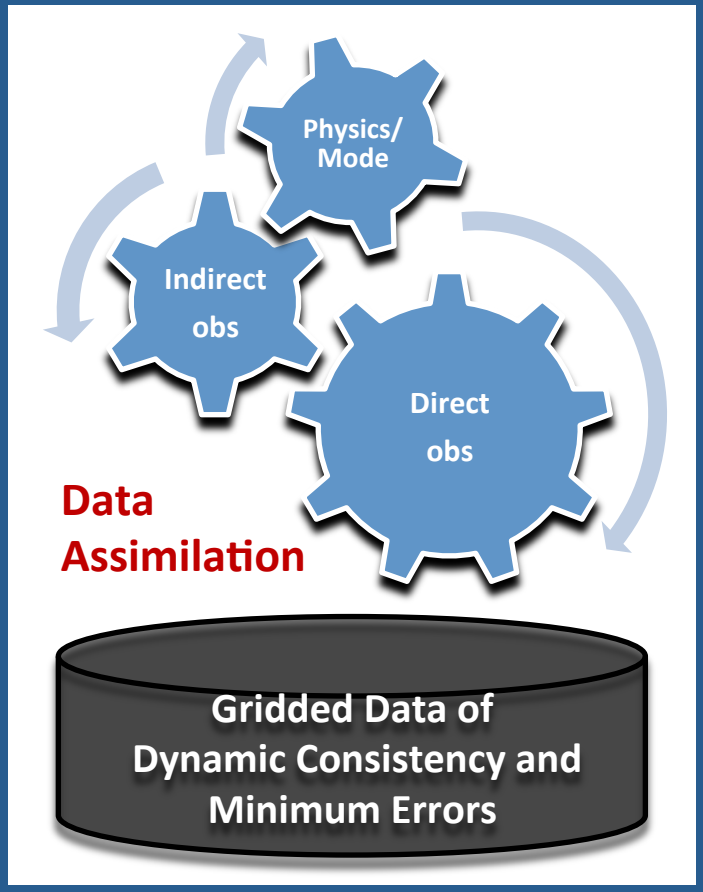
Three domain nested configuration

A resolution of 2 km in the inner domain




**Strategy: Nested WRF at a cloud resolving resolution with multi-scale data assimilation**

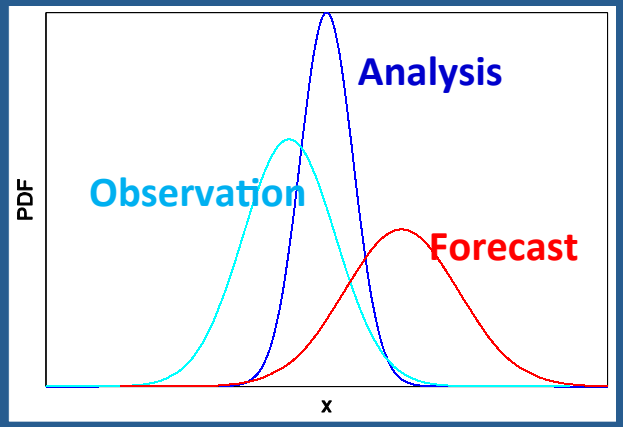
# Conventional Data Assimilation: Optimal Estimation




$$\min_x J = \frac{1}{2}(x - x^f)^T B^{-1}(x - x^f) + \frac{1}{2}(Hx - y)^T R^{-1}(Hx - y)$$

Background/Forecast — Observation

***B, R*** **- background and observational error covariance**

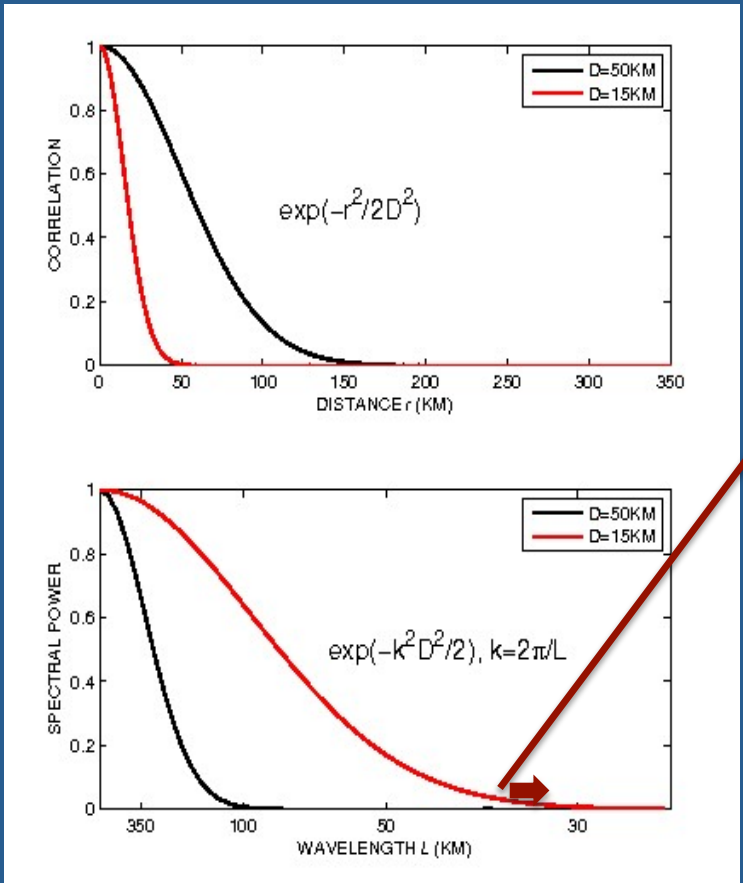



**Maximum Likelihood**

**Last two decades have witnessed great progress in data assimilation**

- **Variational methods (3Dvar/4Dvar)**
- **Sequential methods (Kalman filter/smoother)**

# Data Assimilation for High-Resolution Model




1. Meso- and small- scale systems are intensive, but are localized and intermittently occur.
2. The forecast/background error covariance is primarily determined by large scale systems
3. The correlation scale is inevitable to be large scale

**Conventional data assimilation is ineffective to correct small-scale errors**

(Li et al., 2015, IJNMF)

# A Multi-Scale Three-Dimensional Variational Data Assimilation (MS-DA) System

**Decomposition of Large and small scales**

$$x = x_L + x_S$$

$$\min_x J(\delta x) = \frac{1}{2}\delta x^T \left(B_L + B_S\right)^{-1}\delta x + \frac{1}{2}(H\delta x - \delta y)^T R^{-1}(H\delta x - \delta y)$$

North America Regional Reanalysis (NARR, NAM, …)

$$\min_{\delta x_L} J(\delta x_L) = \frac{1}{2}\delta x_L{}^T B_L^{-1}\delta x_L + \frac{1}{2}(H\delta x_L - \delta y)^T \left(HB_S H^T + R\right)^{-1}(H\delta x_L - \delta y)$$

$$\min_{\delta x_S} J(\delta x_S) = \frac{1}{2}\delta x_S{}^T B_S^{-1}\delta x_S + \frac{1}{2}(H\delta x_S - \delta y)^T \left(HB_L H^T + R\right)^{-1}(H\delta x_S - \delta y)$$

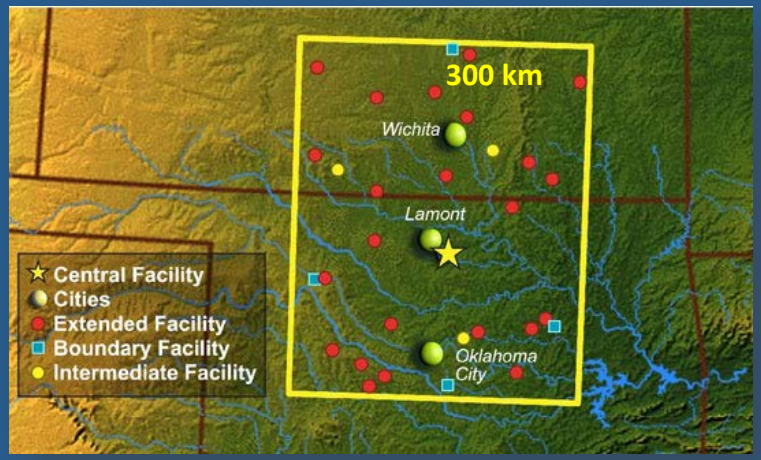
Small scale data assimilation

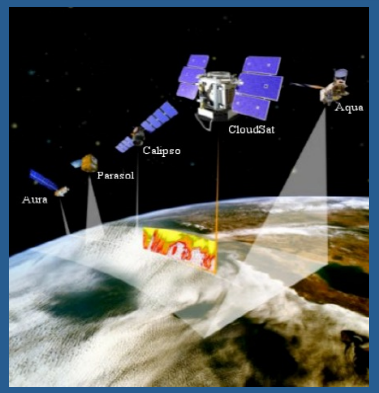
1. Enhanced effectiveness of assimilating ARM dense observations
2. Leveraging existing reanalysis
3. Developed on top of the NCEP WRF GSI

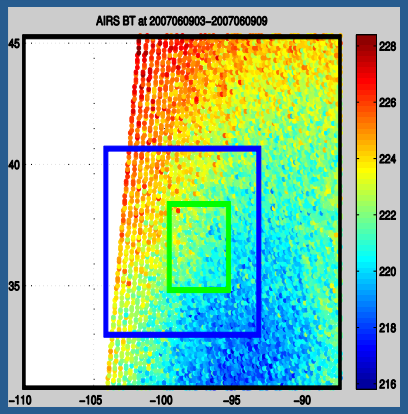
(Li et al. 2015 MWR; 2015, JGR)

# Assimilation of Observations from ARM Facility and Meteorological Observing Networks

- **ARM observations**
  - Balloon-Borne Sounding System (SONDE)
  - Soil Water And Temperature System (SWATS)
  - atmospheric emitted radiance interferometer (AERI)
  - …
- **Processed conventional data (NCEP)**
- **Processed satellite data (NCEP)**
  - Microwave Radiances (Brightness Temp)
  - High-resolution infrared radiances



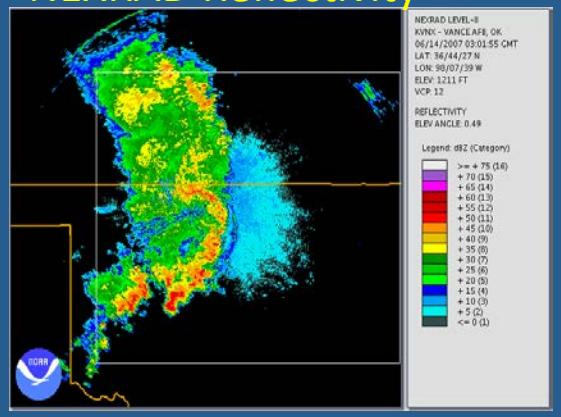




**Atmospheric Infrared Sounder (AIRS)**

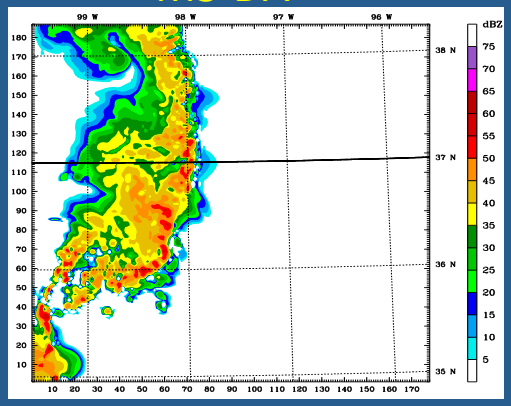
# Improvement on Simulation of Mesoscale Systems Using the Multi-Scale DA

**6 UTC, 14 June, 2007**

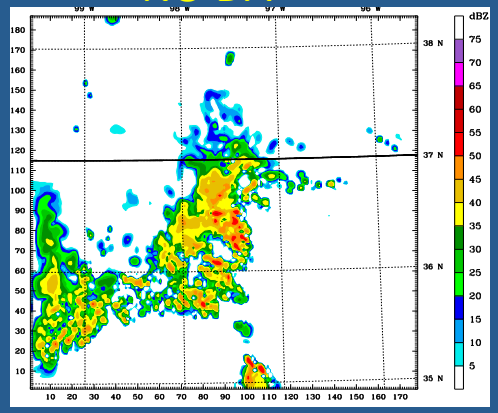
NEXRAD Reflectivity



MS-DA



NO DA

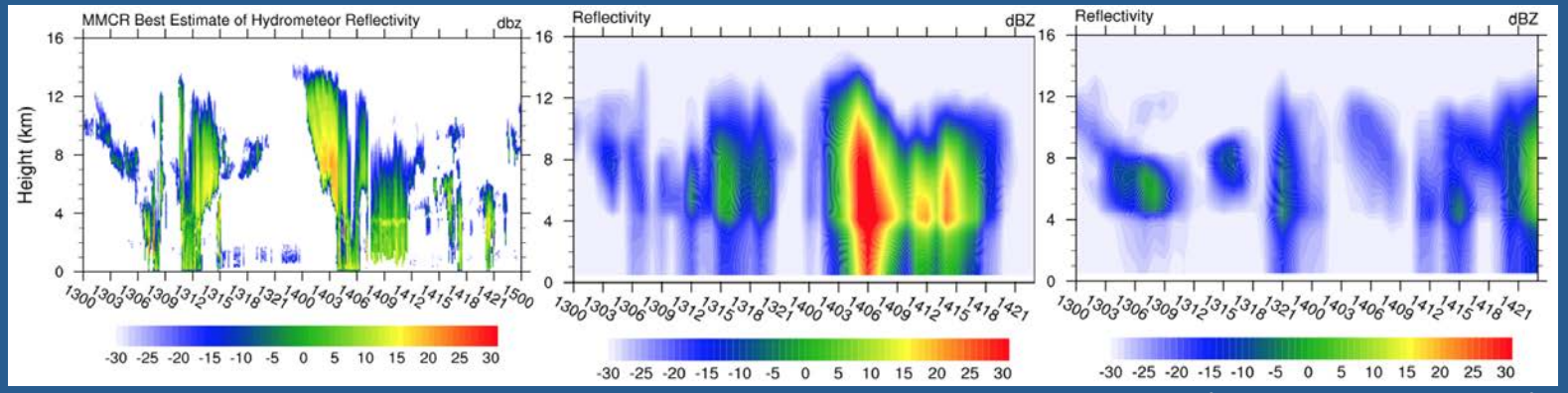


**Time evolution of reflectivity profiles**

OBS

MS-DA

NO DA

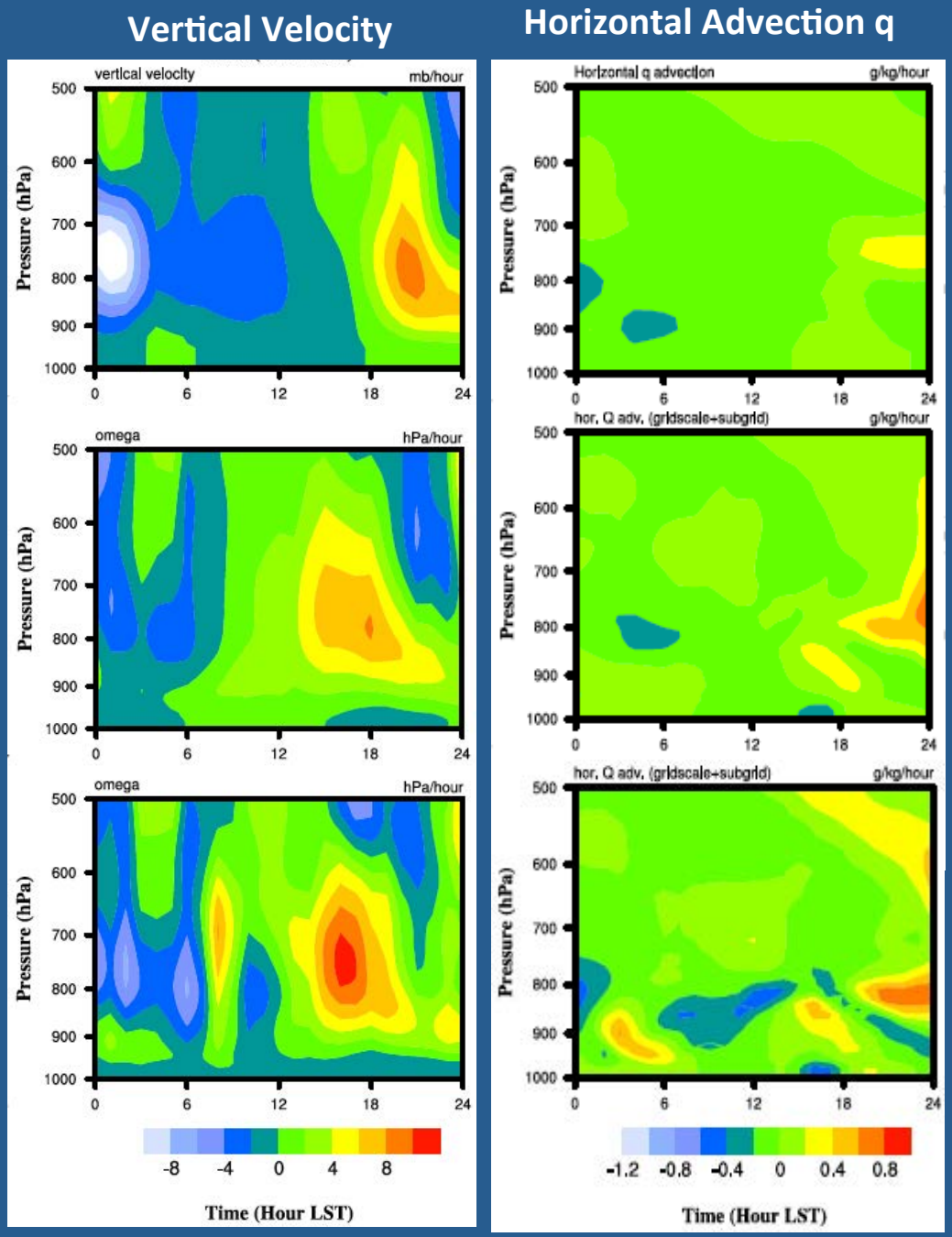



(Li et al., 2015, JGR)

# Large Scale Forcing: Spatial Scale Awareness

Large scale forcing depends on the domain dimension over which the average is derived.

What should the domain dimension be ?



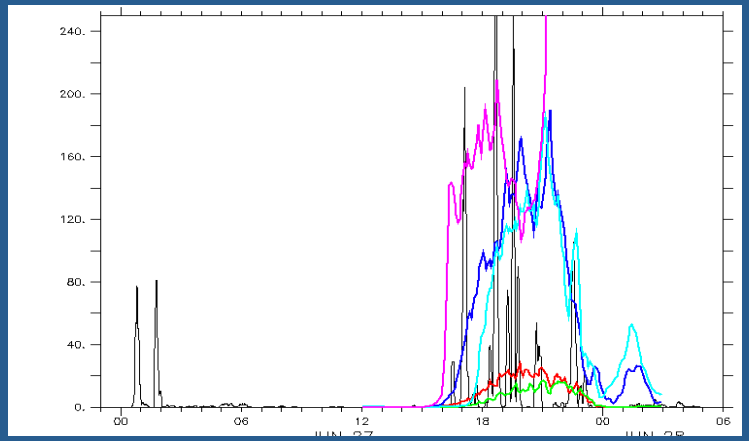
# Summary

- Implementation and optimization of a multiscale data assimilation (MS-DA) scheme in a cloud-resolving WRF.
- Ensemble of large scale forcing derived from MS-DA analyses, and also from weather forecast products and ARM variational analyses.
- Development of the LES ARM Symbiotic Simulation and Observation (LASSO) Workflow using both WRF and SAM in progress
- Preliminary tests showing the that LES simulation ensemble displays sensitivities to large scale forcing and initialization

Gustafson, et al., Poster A21D-0161 for Workflow

Vogelmann et al., Poster A21D-0163 for 4D Cube

**Liquid Water Path**




Observation (black) and WRF LES Simulations (color) using different forcing